Tectonophysics 644–645 (2015) 122–137

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Magnetostratigraphic record of the early evolution of the southwestern Tian Shan foreland basin (Ulugqat area), interactions with Pamir indentation and India–Asia collision

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ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form 6 January 2015
Accepted 10 January 2015
Available online 24 January 2015

Keywords:
Magnetostratigraphy
Cenozoic
Tian Shan
Pamir
Tarim Basin
Tectonics

ABSTRACT

The Tian Shan range is an inherited intracontinental structure reactivated by the far-field effects of the India–Asia collision. A growing body of thermochronology and magnetostratigraphy datasets shows that the range grew through several tectonic pulses since ~25 Ma, however the early Cenozoic history remains poorly constrained. The time-lag between the Eocene India–Asia collision and the Miocene onset of Tian Shan exhumation is particularly enigmatic. This peculiar period is potentially recorded along the southwestern Tian Shan piedmont. There, late Eocene marine deposits of the proto-Paratethys epicontinental sea transition to continental foreland basin sediments of unknown age were recently dated. We provide magnetostratigraphic dating of these continental sediments from the 1700-m-thick Mine section integrated with previously published detrital apatite fission track and U/Pb zircon ages. The most likely correlation to the geomagnetic polarity time scale indicates an age span from 20.8 to 13.3 Ma with a marked increase in accumulation rates at 19–18 Ma. This implies that the entire Oligocene period is missing between the last marine and first continental sediments, as suggested by previous southwestern Tian Shan results. This differs from the southwestern Tarim basin where Eocene marine deposits are continuously overlain by late Eocene–Oligocene continental sediments. This supports a simple evolution model of the western Tarim basin with Eocene–Oligocene foreland basin activation to the south related to northward thrusting of the Kunlun Shan, followed by early Miocene activation of northern foreland basin related to overthrusting of the south Tian Shan. Our data also support southward propagation of the Tian Shan piedmont from 20 to 18 Ma that may relate to motion on the Talas Fergana Fault. The coeval activation of a major right-lateral strike-slip system allowing indentation of the Pamir Salient into the Tarim basin, suggests far-field deformation from the India–Asia collision zone affected the Tian Shan and the Talas Fergana fault by early Miocene.

1. Introduction

The Tian Shan is a 2500-km-long, up to 7400-m-high range extending through western China, Kazakhstan, and Kyrgyzstan. This range belongs to the larger Central Asian Orogenic Belt (CAOB) extending from the Urals to the Pacific across the East European, Siberian, North China, and Tarim cratons (e.g. Jolivet et al., 2010; Şengör et al., 1993; Windley et al., 2007). Cenozoic tectonic deformation of the Tian Shan is predominantly attributed to tectonic rejuvenation in response to the far-field effects of the India–Asia collision (e.g. Avouac et al., 1993; Huang et al., 2010; Patriat and Achache, 1984; Sun et al., 2009; Tapponnier et al., 2001; Van Hinsbergen et al., 2011; Yin et al., 1998). Thick Cenozoic accumulations of sediments derived mostly from the uplifting mountain range form the terrigenous depositional sequences that are well preserved and exposed in foreland basins of the Tian Shan (Charreau et al., 2009; Fang et al., 2005, 2006; Hendrix, 2000; Wu et al., 2006; Yang et al., 2013). The Tian Shan has provided an ideal setting for understanding Cenozoic intracontinental deformation in central Asia and the associated effects on regional environment and global climate. However, vigorous debate and gaps in understanding still exist concerning the Cenozoic history and driving mechanism of the Tian Shan orogeny arising mainly from the lack of accurate constraints on the exact time of deformation, uplift, and associated deposition. In particular, the early Cenozoic history of the range is poorly constrained. While the onset of exhumation is fairly well constrained

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http://dx.doi.org/10.1016/j.tecto.2015.01.003
0040-1951/

to have occurred at around the Oligo-Miocene boundary, it remains unclear what happened before that and why deformation accelerated only in the Middle to Late Miocene. More fundamentally, it remains unresolved why deformation from the India–Asia collision starting in the Eocene (ca. 50 Ma) propagated to the Tian Shan only in the early Miocene over 25 Myrs later.

Apatite fission track analyses from basement and sediments in the Tian Shan, as well as its piedmonts, predominately suggest an initiation of rapid uplift at ~25–20 Ma (e.g. Amidon and Hynek, 2010; Dumitru et al., 2001; Hendrix et al., 1994; Sobel and Dumitru, 1997; Sobel et al., 2006). Furthermore, Bullen et al. (2001, 2003) demonstrated that exhumation of the Kyrgyz Tian Shan continued at ~11 Ma, and younger exhumation ages ranging between 6 and 8 Ma are also reported from the Chinese Southwest Tian Shan (e.g. Wang et al., 2010). Recent magnetostratigraphic studies have also been conducted on Cenozoic sediments from both the northern and southern piedmonts of the Tian Shan. Several main pulses in increased sedimentation rate were detected, reflecting the multi-phased uplift and deformation of the Tian Shan at ~26–23 Ma, ~17–16 Ma, ~13–11 Ma, ~7 Ma and ~4 Ma (e.g. Bullen et al., 2001; Charreau et al., 2005; Huang et al., 2006, 2010; Jin et al., 2008; Li et al., 2011; Lu et al., 2010; Sun et al., 2004, 2009). However, these studies have concentrated on the Miocene and later Tian Shan evolution focusing on correctly constraining the Cenozoic episodic uplift of the Tian Shan. What happened in the period between the Eocene India–Asia collision and the Miocene Tian Shan exhumation remains to be explored.

In that period, recent studies have focused on the record of the westward retreat of the vast epicontinental sea that covered the Tarim Basin at the eastern end of a shallow sea that formerly extended across the Eurasian continent (e.g. Bosboom et al., 2011; Garzione et al., 2005; Graham et al., 2005; Kent-Corson et al., 2009; Ramstein et al., 1997; Zhang et al., 2007). Accurate age estimates on the youngest marine sediments indicate final sea retreat from the northern Tarim basin in the late Eocene (Bosboom et al., 2014a). However, it remains unclear what happened between the deposition of these last marine deposits and the overlying continental deposits as the latter are virtually unconstrained in age. They have been usually attributed an Oligocene to Miocene age based mainly on the fact that they lie on marine sediments of Eocene age and are overlain by Miocene series.

In this paper, we report a detailed magnetostratigraphic study of such continental sediments at the Mine section located in the Ulugqat area in the piedmont of the Southwest Tian Shan (Fig. 1). This section has been chosen because it lies directly on dated marine deposits (Bosboom et al., 2014a) thus providing a basal age constraint and because it encompasses a complete and well developed sequence of the early continental deposits with a total thickness of ~1700 m. This section also has previously published detrital Apatite Fission Track (AFT) ages and detrital U/Pb zircons ages that provide additional age and provenance information (Yang et al., 2014).

2. Regional stratigraphic and geological setting

A series of representative forelands, characterized by well-preserved infillings of Cenozoic sediments, were deposited along the margins of the Pamir, western Kunlun and Southwest Chinese Tian Shan (SWTS), such as the Kuqa subbasin (e.g. Heermance et al., 2007; Li et al., 2004), the Fergana–Alai Basin (e.g. Burtman, 2000; De Grave et al., 2012), and the Afghan–Tadjik Basin (e.g. Thomas et al., 1994) from east to west. These basins are clearly related to significant Miocene deformation widely developed diachronously across these basins characterized by increasing accumulations rates recorded throughout Miocene times (Amidon and Hynek, 2010; Heermance et al., 2007; Li et al., 2011; Liao et al., 2012; Sobel and Dumitru, 1997; Sobel et al., 2006; Yin et al., 2002). Underlying these Miocene strata, poorly dated late Paleogene to early Neogene sediments are regionally extensive suggesting that they were part of a larger basin that was later segmented. Although age constraints are still lacking, these strata have been correlated regionally across basins from Central Asia based mainly on lithofacies and marine micro- and macro-fossil assemblages (Table 1; Bosboom et al., 2011, 2014a,b; Coutand et al., 2002; Jia et al., 2004). Due to this lack of age constraints it remains unclear whether these strata can be associated with an enigmatic Eocene–Oligocene regional tectonic phase or to the onset of the ensuing Miocene tectonism.

The study area is located at the junction of the Southwest Tian Shan to the north and the western Kunlun/northern Pamir to the south, whose tectonic evolution is summarized as follows.

To the north of the study area, the east–west trending Tian Shan extends through western China, Kazakhstan and Kyrgyzstan and represents an important part of the Central Asian Orogenic Belt (CAOB). The topographic evolution of the Tian Shan has been the focus of considerable attention leading to the interpretation that it formed during Late Cenozoic times as a result of the distant effects of the ongoing India–Eurasia collision (e.g. Avouac et al., 1993; Burchfiel and Royden, 1991; Burchfiel et al., 1999; Buslov et al., 2004, 2007; Dumitru et al., 2001; Jolivet et al., 2010; Molnar and Tapponnier, 1975; Tapponnier and Molnar, 1977; Wei et al., 2014; Yin et al., 1998). The Southwest Chinese Tian Shan (SWTS) is characterized by ~9 km of Cenozoic sediments accumulated in a foreland basin setting forming the northwestern part of the Tarim Basin (e.g. Chen et al., 2002; Heermance et al., 2007). Cenozoic deformation, shortening, and uplift in the SWTS and its piedmonts are interpreted to have commenced at ~25–20 Ma, as indicated by significant exhumation around the Oligocene–Miocene boundary (e.g. Hendrix et al., 1994; Ji et al., 2008; Sobel, 1995; Sobel and Dumitru, 1997; Sobel et al., 2006; Yin et al., 1998). Subsequently, renewed exhumation at 19 $\pm$ 3 Ma is reported in the SWTS (Heermance et al., 2007; Sobel et al., 2006) and a southward propagation of deformation indicated by diachronous deposition of alluvial fan conglomerates and several abrupt increases in accumulation rates respectively at ~16, 13 Ma, and 4 Ma (Heermance et al., 2007; Li et al., 2011). To the south of the study area is the eastern limb of the Pamir salient orogenic belt. It is also referred as the western Kunlun Shan and extends from the northern margin of the Tibetan Plateau to the south to the Tian Shan along the southwestern margin of the Tarim Basin. The timing of indentation of the Pamir salient, and in particular its relation with the Tian Shan, remains poorly understood, and has important implications on Paratethys sea retreat, Asian climate and tectonism (e.g. Bosboom et al., 2011, 2014a,b,c; Sobel et al., 2013). It is generally assumed that the far-field effects of the India–Eurasia collision induced multiple stages of uplift and erosion during the Cenozoic within the western Kunlun and Pamir (Amidon and Hynek, 2010; Burtman and Molnar, 1993; Cui et al., 2006; Jolivet et al., 2001; Liu et al., 2010; Sobel and Dumitru, 1997; Sobel et al., 2011, 2013; Wang et al., 2006). Sobel and Dumitru (1997) and Yin et al. (2002) initially suggested that strong exhumation and cooling occurred during the latest Oligocene to Middle Miocene, based on sedimentary facies, provenance changes, and thermochronological data from the southwestern Tarim Basin. Recent thermochronological data results suggest a more complex exhumation and deformation pattern, divided into three stages: the Late Oligocene to Early Miocene (Cao et al., 2009; Li et al., 2007; Liu et al., 2010), the Middle to Late Miocene (Cao et al., 2009; Liu et al., 2010; Wang et al., 1999, 2001, 2002) and the Late Miocene to present day (e.g. Cao et al., 2009; Li et al., 2005, 2007; Liu et al., 2010). Additionally, the interaction between the Pamir and the SWTS changed the sedimentation and drainage patterns (Zheng et al., 2006). The onset of this change has been recently estimated as Oligocene–Miocene by provenance and thermochronological data but still remains poorly constrained in the sedimentary record (e.g. Cao et al., 2013; Sobel et al., 2011).

3. Age constraints from biostratigraphy

In the study area, Cenozoic strata exposed in the western Tarim consist of: 1) the Kashi Group, which comprises in chronological order the